The Diurnal Variation of Terrestrial Magnetism.

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(Abstract.)

1. In a previous communication* I proved that the diurnal variation of terrestrial magnetism had its origin outside the Earth's surface, and drew the natural conclusion that it was caused by electric currents circulating in the upper regions of the atmosphere. If we endeavour to carry the investigation a step further, and consider the probable origin of these currents, we have at present no alternative to the theory, first proposed by Balfour Stewart, that the necessary electromotive forces are supplied by the permanent forces of terrestrial magnetism acting on the bodily motion of masses of conducting air which cut through its lines of force. In the language of modern electro-dynamics, the periodic magnetic disturbance is due to Foucault currents induced in an oscillating atmosphere by the vertical magnetic force. The problem to be solved in the first instance is the specification of the internal motion of a conducting shell of air, which shall, under the action of given magnetic forces, determine the electric currents producing known electro-magnetic effects. Treating the diurnal and semi-diurnal variations separately, the calculation leads to the interesting results that each of them is caused by an oscillation of the atmosphere which is of the same nature as that which causes the diurnal changes of barometric pressure. The phases of the barometric and magnetic oscillations agree to about $1\frac{3}{4}$ hours, and it is doubtful whether this difference may not be due to uncertainties in the experimental data. In the previous communication referred to, I already tentatively suggested a connection between the barometric and magnetic changes, but it is only recently that I have examined the matter more closely. In the investigation which follows, I begin by considering the possibility that both variations are due to one and the same general oscillation of the atmosphere. The problem is then absolutely determined if the barometric change is known, and we may calculate within certain limits the conducting power of the air which is sufficient and necessary to produce the observed magnetic effects. This conducting power is found to be considerable. It is to be observed, however, that the electric currents producing the magnetic variations circulate only in the upper layers of the atmosphere, where the pressure is too small to affect the barometer; the two variations have their origin,

* 'Phil. Trans.,' A, vol. 180, p. 467 (1889).

therefore, in different layers, which may to some extent oscillate independently. Though we shall find that the facts may be reconciled with the simpler supposition of one united oscillation of the whole shell of air, there are certain difficulties which are most easily explained by assuming possible differences in phase and amplitude between the upper and lower layers. If the two oscillations are quite independent, the conducting power depending on the now unknown amplitude of the periodic motion cannot be calculated, but must still be large unless the amplitude reaches a higher order of magnitude than we have any reason to assume.

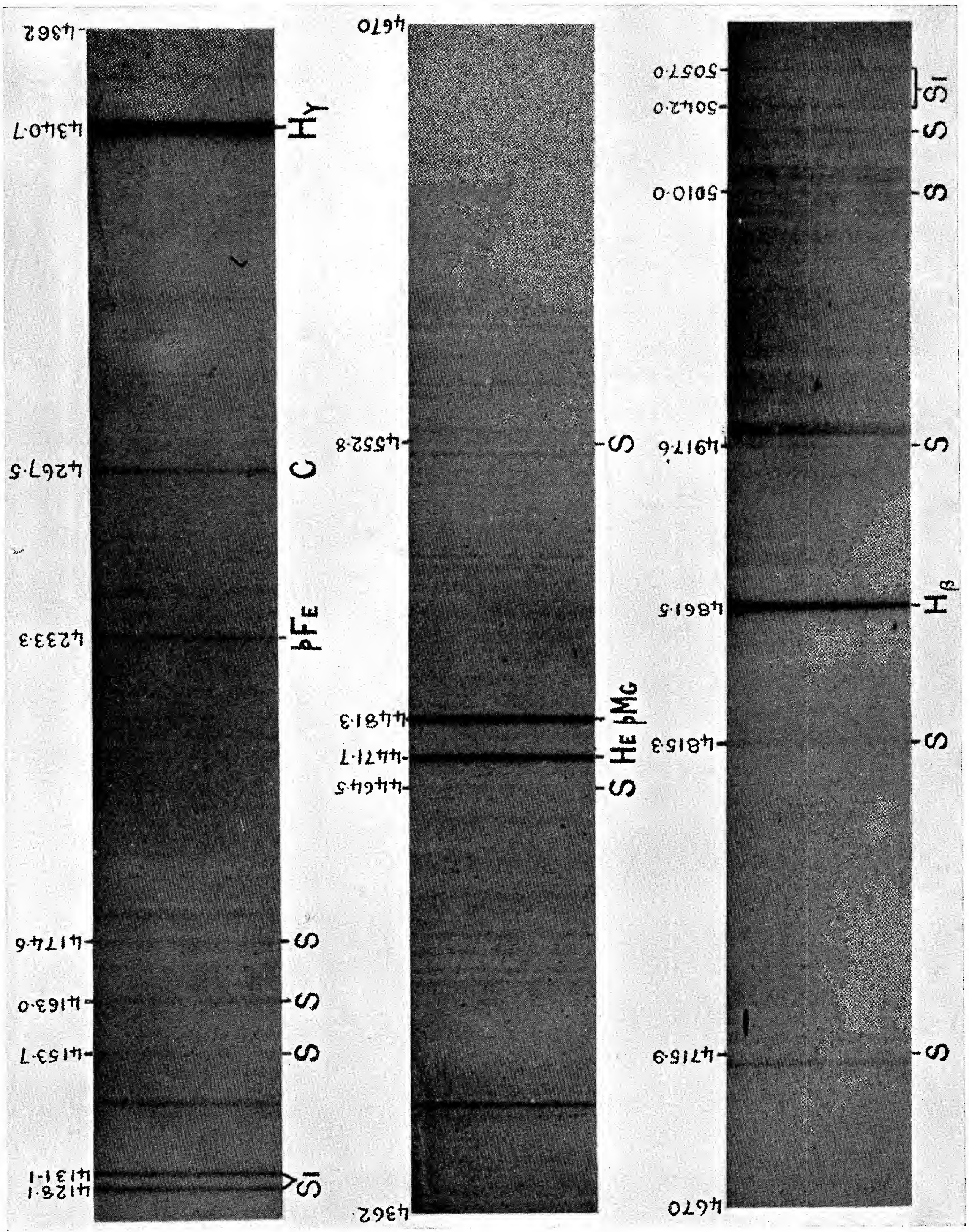
The mathematical analysis is simple so long as we take the electric conductivity of the air to be uniform and constant; but the great ionisation which the theory demands requires some explanation, and solar radiation suggests itself as a possible cause. Hence we might expect an increased conducting power in summer and in day time as compared with that found during winter and at night. Observation shows, indeed, that the amplitude of the magnetic variation is considerably greater in summer than in winter and we know that the needle is at comparative rest during the night. The variable conducting power depending on the position of the sun helps us also to overcome a difficulty which at first sight would appear to exclude the possibility of any close connection between the barometric and magnetic variations; the difficulty is presented by the fact that the change in atmospheric pressure is mainly semi-diurnal, while the greater portion of the magnetic change is diurnal. This may, to some extent, be explained by the mathematical calculation, which shows that the flow of air giving a 24-hourly variation of barometric pressure is more effective in causing a magnetic variation than the corresponding 12-hourly variation, but the whole difference cannot be accounted for in this manner. If, however, the conductivity of air is greater during the day than during the night, it may be proved that the 12-hourly variation of the barometer produces an appreciable periodicity of 24 hours in the magnetic change, while there is no sensible increase in the 12-hourly magnetic change, due to the 24-hourly period of the barometer. The complete solution of the mathematical problem for the case of a conducting power proportional to the cosine of the angle of incidence of the sun's rays is given in Part II. But even this extension of the theory is insufficient to explain entirely the observed increased amplitude of the magnetic variation during summer. We are, therefore, driven to assume either that the atmospheric oscillation of the upper layer is greater in summer than in winter and is to that extent independent of the oscillation of the lower layers, or that the ionising power of solar radiation is to some extent accumulative and that the atmospheric conductivity is, therefore, not com-

pletely determined by the position of the sun at the time. The increased amplitude at times when sunspots are frequent is explained by an increased conductivity corresponding to an increase in solar activity. All indications, therefore, point to the sun as the source of ionisation, and ultra-violet radiation seems to be the most plausible cause.

A good test of the proposed theory may be found in a closer examination of the diurnal magnetic changes in the equatorial regions, because, owing to the inclination of the magnetic to the geographical axis, the magnetic changes ought to have a term which does not depend on local time, but on the time of the meridian containing the geographical and magnetic pole. This term has its greatest importance at the equator and at the time of the equinox. A study of the lunar effects may also lead to interesting conclusions, as, according to the point of view of the present paper, they must be explained by some tidal oscillation.

The value of the conductivity necessary to explain the diurnal variation in the manner indicated depends on the thickness of the layers which carry the currents. If e be the thickness and ρ the conductivity and the amplitude of oscillation in the upper layers is assumed to be the same as that deduced from the barometric variation, it is found that $\rho e = 3 \times 10^{-6}$. If e is equal to 300 kilometres, the conductivity would have to be as high as 10^{-13}, while the observed conductivity of air at the surface of the earth under normal conditions is of the order 10^{-24}; at a height at which the pressure is reduced to one degree per square centimetre, the conductivity would be 10^{-18}, assuming the rate of recombination to be independent of temperature, and the ionising power to be the same. This calculation is based on the assumption that the ions conveying the current are identical with those we observe at high pressures, while it is of course possible that the ionic velocities are much greater. But taking all these possibilities into account, we are led to the conclusion that there must be a powerful ionising agent giving a high conductivity to the upper layer of the atmosphere.

If the fundamental ideas underlying the present enquiry stand the test of further research, we are in possession of a powerful method which will enable us to trace the cosmical causes which affect the ionisation of the upper regions of the atmosphere and which act apparently in sympathy with periodic effects showing themselves on and near the surface of the sun.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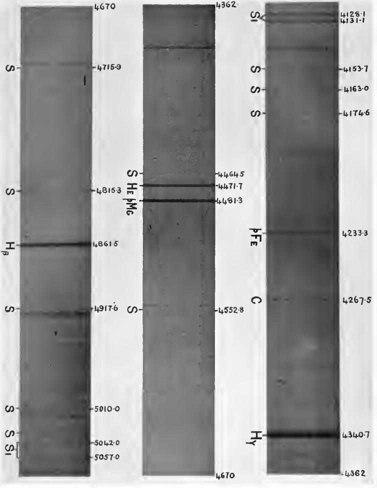

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